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PLASMA IN THE ANTISOLAR REGION OF NEAR-MARTIAN SPACE ACCORDING TO THE MARS-5 SATELLITE MEASUREMENT RESULTS

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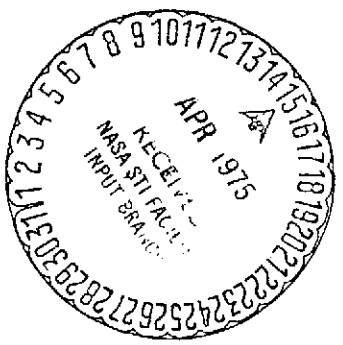

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16. Abstract

This report discusses the preliminary results of sounding measurements of plasma ion and electron components on Mars-5 and Mars-7. The measurements were made in March 1974 in the antisolar region near Mars.

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PLASMA IN THE ANTISOLAR REGION OF NEAR-MARTIAN SPACE ACCORDING TO THE MARS-5 SATELLITE MEASUREMENT RESULTS

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/791*

In 1971-1972 measurements, carried out on the Mars satellites — the interplanetary stations Mars-2 and Mars-3 — established the existence of an outgoing shock wave, which was the result of the interaction between the solar wind and the planet. This was studied both on measurement data of the electron component of the solar wind [1,2] and its ion component [3,4], as well as on data from magnetic measurements [5,6].

This report uses the preliminary results of sounding measurements of the plasma ion and electron component performed on the interplanetary stations Mars-5 (which became a satellite of Mars on 13 February 1974) and Mars-7 (which performed measurements on the Earth-Mars orbit trajectory during a flight close to the planet on 9 March 1974, which were continued beyond the orbit of Mars). All of the stations launched toward Mars in 1973 carried identical equipment — ion modulation traps using the method of braking potentials. Their characteristics and location on the spacecraft are described in [7]. We shall give certain data from new measurements of the position of the boundaries and the characteristics of the transition

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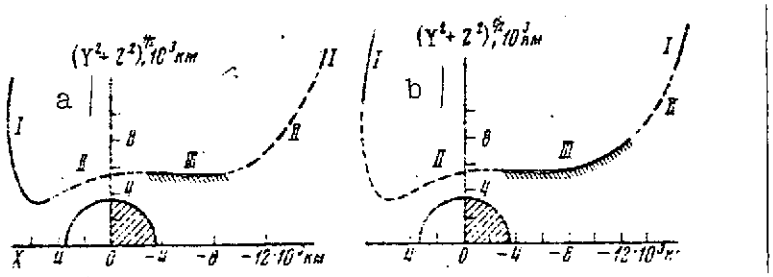

Figure 1. Sections of Mars-5 trajectory close to the planet on 13 February 1974 (a) and 14 February 1974 (b). The dashed line corresponds to orbit sections on which plasma measurements were not carried out.

layer behind the shock wave front, as well as from the first measurements of characteristics of the plasma formation located beyond the internal boundary of the transition layer in the antisolar part of near-Martian space.

Figure 1 (the X axis passes through the planet center and is directed toward the Sun) shows sections of the Mars-5 trajectories during two consecutive revolutions around the planet (orbit pericenter height of 1800 km, apocenter - 32,000 km, inclination to the equatorial plane ∿ 35°, and period of rotation ∿ 25 hours). An analysis of the ion and electron energy spectra on the satellite orbit sections shown in Figure 1 (and also for all the remaining revolutions of the satellite) showed that close to /792 the planet there are three zones I-III intersected by the satellite, with very differing plasma properties. Typical forms of the primary ion spectra and the curves for the electron braking, corresponding to the three zones, are shown in Figure 2. The characteristics of zones I, II correspond to the characteristics of zone III observed in 1971-1972 on the Mars-2 and Mars-3 satellites, observed at Sun-Mars-satellite angles of more than 90°, which were measured first.

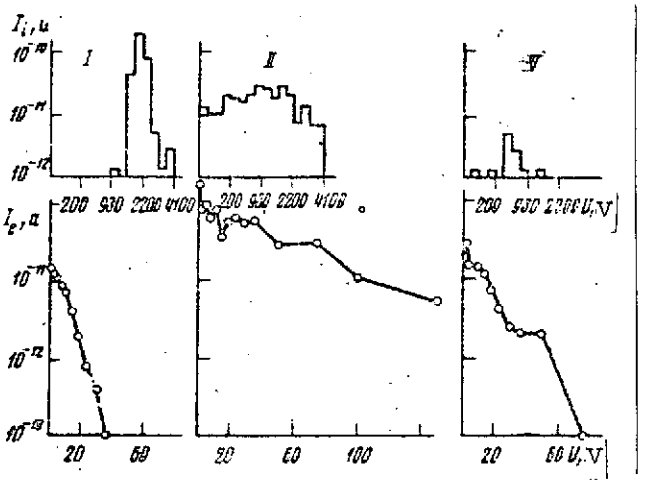

Figure 2. Typical ion spectra and curves for electron braking in I-III zones.

In zone I spectra were recorded corresponding to the unperturbed solar wind. The plasma characteristics in zone II are typical for the transition layer behind a shock wave front: as compared with an unperturbed solar wind, there is a sharp increase in the measured fluxes of electrons and ions, the ion spectra have a clear Maxwell distribution, and the electron temperature T_e greatly increases. The boundary between zones I and II may be reliably identified with the shock wave front.

For zone III (Figure 1, 2) there is a characteristic sharp decrease in the ion currents as compared with zones I and II. A decrease in the measured ion currents is so great that, over approximately 30% of the orbit sections, the ion fluxes in zone III are below the sensitivity limits of the equipment and only on 40% of the orbit are the ions recorded reliably (the recording level exceeds by a factor of three and more the minimum telemetric recording). The T_e values of the electron currents in the zone III are decreased as compared with the zone II. However, they are higher than in the unperturbed zone I (see Figure 2) and are always recorded.

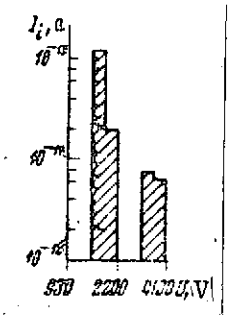

Figure 3. Ion spectrum with minimum ion flux in the period 12-14 February 1974 based on data from Mars-7.

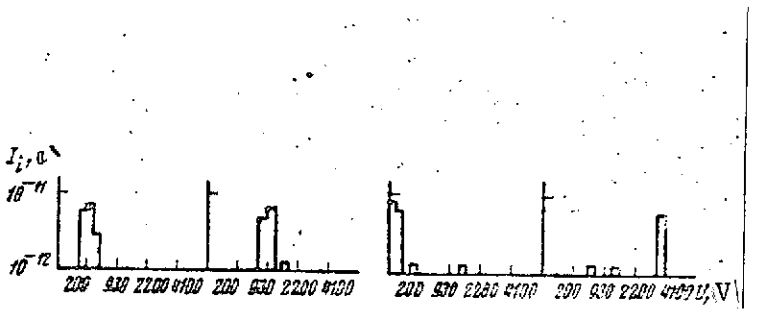

Figure 4. Examples of ion spectra recorded in zone III.

Figure 3 shows one of the ion spectra with an ion flux which was at a minimum on 12-14 February 1974 based on measurement data obtained from identical equipment on the Mars-7 station. This station was on a trajectory to Mars at a distance of ~$5 \cdot 10^6$ km from the planet. It may be seen that the minimum fluxes of the solar wind recorded on this equipment in a solar wind unperturbed by the planet greatly exceed the fluxes characteristic for zone III.

It may be seen from Figure 1 that the section of the orbit intersecting zone III on 14 February 1974 corresponded to $(Y^2+Z^2)^{1/2}$ values from ~5800 km to ~8000 km, i.e., to an interval of distances from the Sun-Mars line of more than 2,000 km. Along the X axis, it extended for no less than several radii of Mars.

Let us turn to the physical characteristics of zone III whose data were obtained first. It was noted above that the ion currents recorded in this zone were much less than in zone I, and there were more electron currents. Thus, the ion energies were

much more variable (as a rule below, and sometimes above, that in zone I; see Figure 4). The significant electron currents recorded point to a high concentration of electrons in zone III. Under these conditions a sharp decrease in the ion currents in the modulation ion trap may occur in two cases: either a directed ion flux changes its direction and is thus very high, because the ion trap is a wide-angled trap (see [7]), or it becomes quasi-isotropic. We should note that a change in the plasma direction or its becoming isotropic must not have a great influence upon the electron currents recorded since the electron flux is quasi-isotropic even in the unperturbed solar wind. The angular characteristic of the ion trap is such that isotropization of the ion flux must decrease the ion current recorded by a factor of approximately 20 as compared with a cold ion flux which is normal to the trap aperture (see the equipment characteristics in [7]). /793

A comparison of the results of the plasma measurements with the data of magnetic measurements performed at the same time on Mars-5 [3], showed the following:

1) The magnetic data also indicates the presence of three different zones along the satellite orbit section close to the planet;

2) The boundaries between the zones coincide, based on data from these and other measurements;

3) For zone III there is a characteristic decrease in the magnetic field fluctuations (which are very great in zone II), and the vector component of the magnetic field predominates in the Sun-Mars direction (sometimes at point 2' this component changes sign, see [8], Figure 3). This led the authors of [8] to relate zone III to the tail of the Martian magnetosphere.

There are two possible assumptions regarding the nature of the plasma zone III: it may either pertain to a "plasma layer" similar to that existing in the central portion of the tail of the Earth's magnetosphere (see, for example, [9, 10]), or to the boundary layer between the transition layer behind the shock wave front and the magnetosphere of Mars, which is similar to the layer observed in the tail of the Earth's magnetosphere [10, 11].

If this is a boundary layer, then the plasma direction in it must be antisolar [9, 10]. Since the ion trap during the measurements was oriented towards the Sun (see [7]), the observed decrease in the ion currents recorded must be explained by a real substantial decrease in the concentration or velocity of ions, or their simultaneous decrease as compared with zones I and II. Although a decrease in the average velocity of ions may be seen based on their variable spectra in zone III, nevertheless, to explain the observed decrease in the ion currents in this case it is necessary to assume that there is a great decrease in the plasma concentration in zone III as compared with zone I. /794
However, if this were the case, it would be difficult to explain why in zone III the electron currents are always recorded which are larger than in zone I.

If zone III is a plasma layer in the tail of the Martian magnetosphere, then recording small ion currents may be explained by the high isotropic nature of ions in this zone, which has an analogy to the plasma layer of the tail of the Earth's magnetosphere. The contradiction between the simultaneous recording of small ion and large electron currents is thus minimized.

A very large (by 30° - 40°) rotation of the directional velocity of the plasma flux on the boundary between zones II and III would be compatible with recording large electron currents.

This would lead to a sharp decrease in the ion currents observed; however, it is difficult to find a basis for this assumption.

Thus, at the present time it is most probable to assume that zone III pertains to the plasma layer of the tail of the Martian magnetosphere, in which ions just like electrons are quasi-isotropic and which is adjacent to the transition layer (zone II).

In the Earth's magnetosphere, the energy of the isotropic ions of the plasma layer $E_i > E_{i0}$, where E_{10} is the ion energy in the unperturbed solar wind ($E_1 \sim 6$ keV, see [11]). In zone III described here $E_i < E_{i0}$, although the electrons are accelerated as compared with the solar wind (see Figure 2). This difference from the Earth's magnetosphere may be related to the fact that the magnetic field of Mars is relatively small and cannot accelerate the ions.

The authors of [4] observed several single ion spectra with reduced ion velocities in the antisolar part of the near-Martian space. They attributed this to the existence of a "boundary layer" formed by viscous interaction of plasma fluxes of the transition layer with the plasma dissipating from the ionosphere of Mars. Since the authors of [4] did not use data about the electron plasma component, due to the narrow angular diaphragm of their ion detectors they could not establish the real physical characteristics of the region examined.

A study of the positions of the fronts of a circumplanetary shock wave, which were observed based on data of the traps of charged particles during different revolutions of Mars-5 around the planet, confirms the conclusion based on plasma observations in [2, 12] that the eigen magnetic field of Mars is the most likely reason for the formation of an outgoing shock wave. This

conclusion is in agreement with the results given in [5, 6, 8].

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